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Efficacy Analysis of Sodium Bicarbonate in the Treatment of Shock Patients: A Systematic Review and Meta-Analysis

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Abstract

Background: Fluid resuscitation represents conventional therapy for shock; however, the optimal fluid choice remains controversial. Sodium bicarbonate administration during resuscitation has shown potential benefits in modulating acidosis and hemodynamic parameters. This study aims to evaluate the clinical effects of sodium bicarbonate compared to conventional resuscitation fluids in patients with shock. We conducted a comprehensive literature search across the PubMed, Embase, Web of Science, and China National Knowledge Infrastructure (CNKI) databases, encompassing studies published in both Chinese and English. Publication bias was assessed using funnel plots and Egger's test. Sensitivity analyses were performed to evaluate the robustness of the findings. For studies exhibiting substantial heterogeneity, meta-regression was applied to explore potential sources of variability. Subgroup analyses examined the influence of shock type, control interventions, and temporal factors. A total of 4137 articles were reviewed. Ultimately, 18 studies meeting the predefined inclusion criteria were selected for analysis, comprising data from 1411 participants. Analysis of the included studies indicated that Sodium bicarbonate administration was associated with a reduction in the duration of intensive care unit (ICU) stay (MD = −1.42 days, 95% CI: −1.87 to −0.97) and total hospitalization length (MD = −2.78 days, 95% CI: −4.33 to −1.23). Sodium bicarbonate treatment lowered lactic acid levels (MD = −0.97 mmol/L, 95% CI: −1.28 to −0.67) and decreased the incidence of complications, including multiple organ dysfunction syndrome (MODS), acute respiratory distress syndrome (ARDS), and disseminated intravascular coagulation (DIC). Furthermore, improvements were observed in coagulation parameters, Including thrombin time (TT), activated partial thromboplastin time (APTT), and prothrombin time (PT). The inflammatory response was also attenuated, as evidenced by reduced circulating levels of interleukin-6 (IL-6), interleukin-10 (IL-10), and tumor necrosis factor-alpha (TNF-α).

Conclusion: This study suggests that Sodium bicarbonate may confer potential therapeutic effects in patients with shock compared to alternative interventions. Further research is required to investigate its efficacy across diverse shock etiologies and therapeutic approaches.

Keywords

shock, sodium bicarbonate, meta-analysis, prognosis

Introduction

Shock is characterized by cellular dysfunction and mortality resulting from inadequate tissue perfusion, potentially leading to organ failure. It is classified into four primary types: hypovolemic, distributive, cardiogenic, and obstructive shock. Regardless of etiology, shock is associated with a high mortality rate.[1,2] Research indicates that resuscitating patients in shock with isotonic crystalloid solutions can improve survival rates. Fluid resuscitation represents a cornerstone of shock management; however, the choice of fluids and resuscitation strategies remains a subject of ongoing debate.[3,4] Sodium bicarbonate has been proposed as a potential therapeutic option for shock patients. Proposed mechanisms include: (1) utilization of the HCO_3^- buffer system, bypassing hepatic metabolism, which may enable more rapid correction of acidosis; (2) electrolyte composition of Sodium bicarbonate Ringer's solution closely approximating that of plasma; and (3) metabolism of Sodium bicarbonate generating CO_2, which is predominantly eliminated via respiration.[5,6] Despite these proposed mechanisms, the clinical application of Sodium bicarbonate for shock resuscitation remains controversial.[7–12] Furthermore, robust evidence supporting its efficacy across

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diverse shock etiologies is currently lacking. This systematic review and meta-analysis aims to evaluate the therapeutic effects of Sodium bicarbonate in patients with shock.

Methods

Study Design and Guidelines

This research was performed following the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).[13] The study protocol was pre-registered in the PROSPERO database (reg. no. CRD42019139881).

Search Strategy

A comprehensive search was conducted across PubMed, Web of Science, Embase, and China National Knowledge Infrastructure (CNKI) databases, covering all records up to July 2024. The comprehensive search strategy is detailed in Supplemental Material 1.

Study Selection

Data extraction tables will be designed according to the guidelines outlined in Section 7.3 of the Cochrane Manual. A standardized data extraction form will be created. Both authors will independently extract data from the selected studies. Any discrepancies will be resolved through discussion between the two reviewers or, if necessary, by consulting an independent third-party reviewer to reach a consensus.

The inclusion criteria were: (1) Patients diagnosed with shock,[2,10,14] (2) Studies evaluating the use of sodium bicarbonate as an intervention, (3) Sample sizes of more than ten participants, and (4) Clinical research.

Exclusion criteria included: (1) Case reports, conference abstracts, letters, and expert opinions, (2) Studies without full-text availability, (3) Animal studies, (4) Data that could not be analyzed appropriately, (5) Duplicate publications, (6) Uncontrolled trials, and (7) Studies involving only participants younger than 3 years old.

Risk of Bias Assessment

Two independent reviewers used the Cochrane Collaboration's Risk of Bias (RoB) tool to assess the quality of the studies.[15] The assessment followed the Cochrane Bias Risk tool's criteria, which included: (1) Selection bias, (2) Performance bias, (3) Attrition bias, (4) Detection bias, (5) Reporting bias, and (6) Other bias. For each criterion, the risk was categorized as low, unclear, or high. Any discrepancies between the two reviewers were resolved through discussion with a third author.

Data Extraction

Prior to data collection, a standardized data extraction form was developed. The following information was extracted from each included study:(1) Author(s), publication year, and country; (2) Study design; (3) Participant characteristics; (4) Outcome measures; (5) Sample size (experimental vs control groups); (6) Comparator interventions. Outcomes were categorized as: Primary Outcomes: Survival, lactate levels, length of hospital stay, intensive care unit (ICU) length of stay, multiple organ dysfunction syndrome (MODS), acute respiratory distress syndrome (ARDS), thrombin time (TT), activated partial thromboplastin time (APTT), prothrombin time (PT). Secondary Outcomes: Partial pressure of oxygen (PO_2), partial pressure of carbon dioxide (PCO_2), respiratory rate, heart rate, mean arterial pressure (MAP), Glasgow Coma Scale (GCS) score, pH levels, Sodium bicarbonate levels, bicarbonate ion (HCO_3^-), potassium ion (K^+), chloride ion (Cl^-), disseminated intravascular coagulation (DIC), interleukin-6 (IL-6), interleukin-10 (IL-10), tumor necrosis factor-alpha (TNF-α), shock index. Discrepancies in data extraction were resolved through consensus or adjudication by a third reviewer.

Statistical Analysis

The pooled analysis was conducted using Review Manager 5.4.1 and Stata 17.0. Heterogeneity was assessed using the I^2statistic. An I^2value greater than 50% indicated high heterogeneity, while a value of 50% or less indicated low heterogeneity. A random effects model was applied in cases of high heterogeneity, and a fixed effects model was used for low heterogeneity. For continuous variables, the standardized mean difference (SMD) or mean difference (MD) with a 95% confidence interval (CI) was calculated between the two groups. For binary variables, the odds ratio (OR) and corresponding 95% CI were computed between the two groups. A p-value of less than 0.05 was considered statistically significant.

Results

Study Selection and Evaluation

The study selection process, detailed in the PRISMA flowchart (Figure 1), commenced with 4137 records identified through database searches. After systematic screening, 18 studies met the inclusion criteria.[16–34] Key characteristics of the included studies are detailed in Supplemental Material 2. Methodological quality assessment, conducted using the Cochrane Collaboration's ROB tool (Figure 2).

Survival

Data extraction identified survival outcomes from 10 studies. The pooled analysis (Figure 3), demonstrated good between-group homogeneity ($I^2 = 0\%$), analyzed using a fixed-effect model. Sodium bicarbonate treatment significantly improved survival in shock patients compared to the control group (OR 0.95, 95% CI 1.45 to 2.93, $P < .0001$). Subgroup analyses by shock type were consistent with the overall findings. The funnel plot was symmetrical, and no significant publication bias was detected (Egger test, $P = .093$).

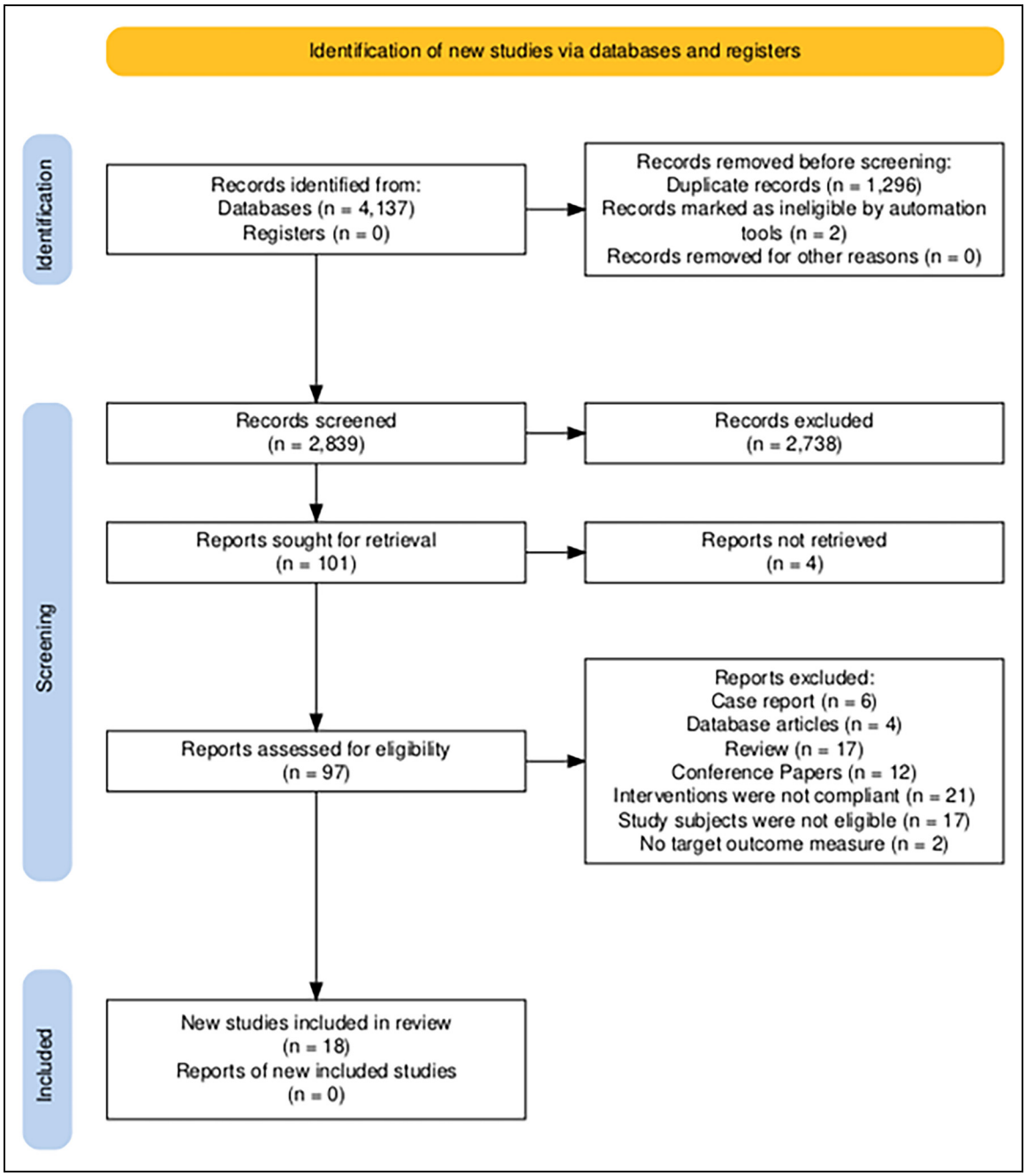
Identification of new studies via databases and registers
Identification
Records identified from:
Databases (n = 4,137)
Registers (n = 0)
Records removed before screening:
Duplicate records (n = 1,296)
Records marked as ineligible by automation tools (n = 2)
Records removed for other reasons (n = 0)
Screening
Records screened
(n = 2,839)
Records excluded
(n = 2,738)
Reports sought for retrieval
(n = 101)
Reports not retrieved
(n = 4)
Reports assessed for eligibility
(n = 97)
Reports excluded:
Case report (n = 6)
Database articles (n = 4)
Review (n = 17)
Conference Papers (n = 12)
Interventions were not compliant (n = 21)
Study subjects were not eligible (n = 17)
No target outcome measure (n = 2)
Included
New studies included in review
(n = 18)
Reports of new included studies
(n = 0)

Figure 1. PRISMA flow diagram of study selection.

Length of Stay

We analyzed two datasets: ICU length of stay and total hospital stay.

ICU Length of Stay

Two studies were pooled (Supplemental Material 3), showing high homogeneity ($I^2 = 0\%$), analyzed with a fixed-effect model. Sodium bicarbonate treatment reduced ICU stay compared to the control group (OR 0.95, 95% CI −1.87 to −0.97, $P < .00001$).

Hospital Length of Stay

Two studies showed similar homogeneity ($I^2 = 0\%$, Supplemental Material 3). Sodium bicarbonate significantly reduced the total hospital stay (OR 0.95, 95% CI −4.33 to −1.23, $P = .0004$).

Lac

Thirteen studies were included in this analysis (Figure 4). Due to significant heterogeneity ($I^2 = 92\%$), a random-effects model was employed, indicating that sodium bicarbonate effectively reduced lactate levels (MD = −0.97; 95% CI: −1.28 to −0.67;

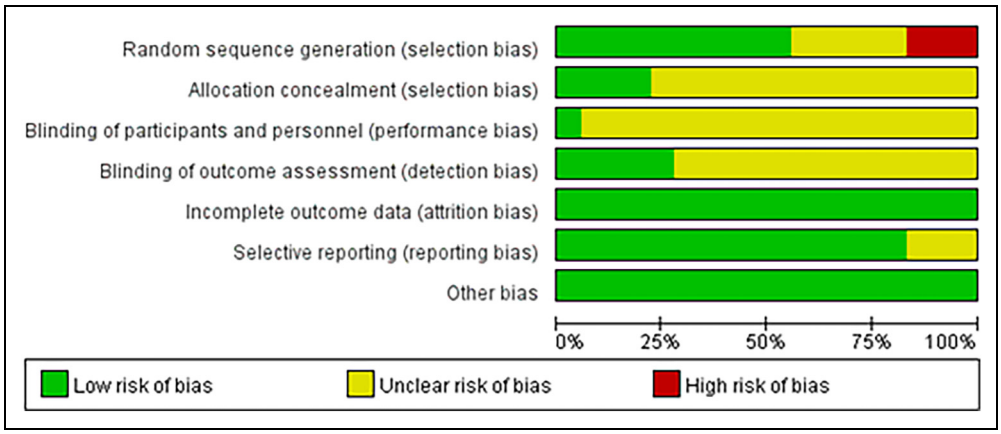

Figure 2. Risk of bias.

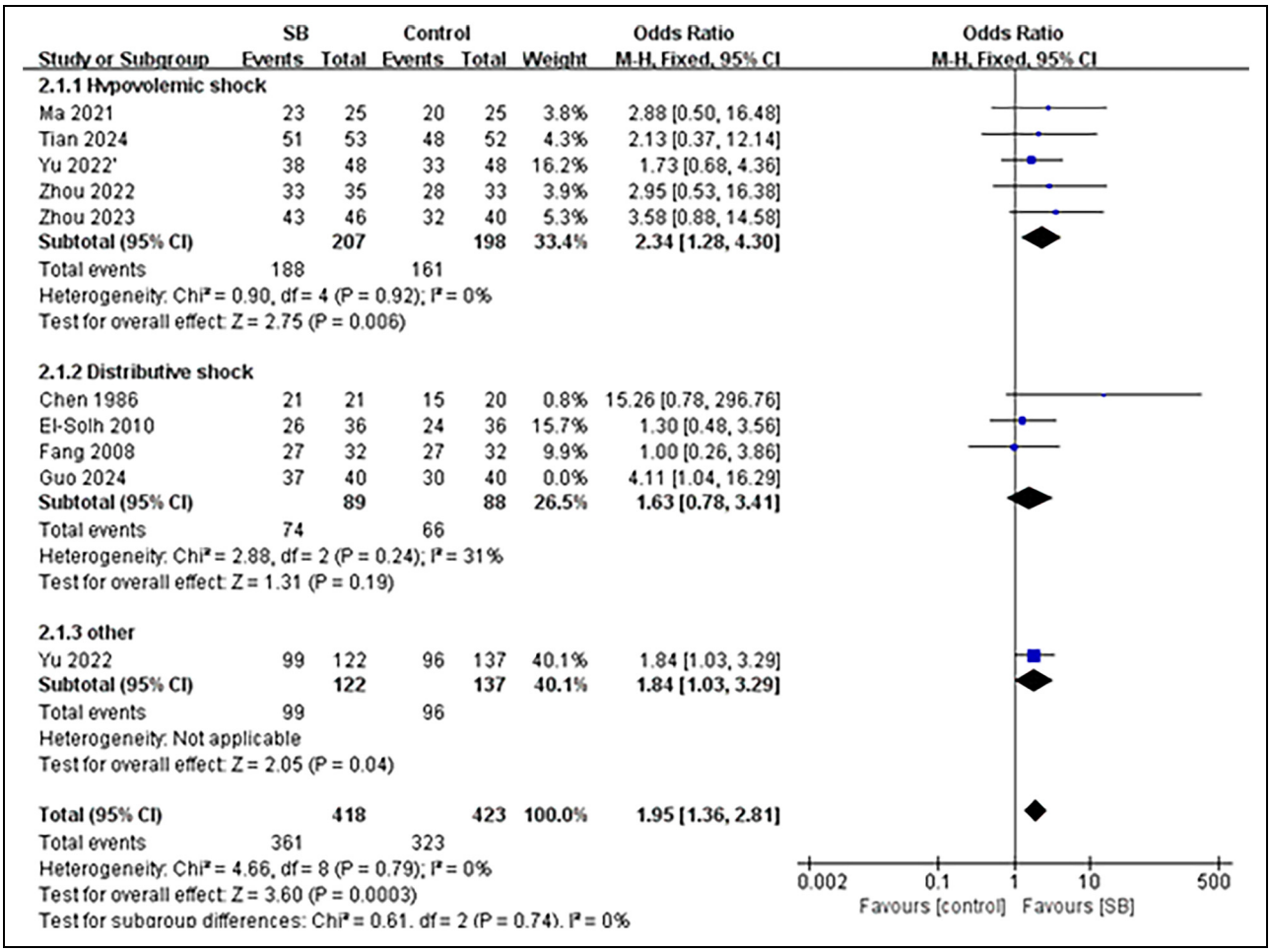
SB
Control
Odds Ratio
Odds Ratio
Study or Subgroup Events Total Events Total Weight M-H, Fixed, 95% CI
M-H, Fixed, 95% CI
2.1.1 Hypovolemic shock
Ma 2021 23 25 20 25 3.8% 2.88 [0.50, 16.48]
Tian 2024 51 53 48 52 4.3% 2.13 [0.37, 12.14]
Yu 2022' 38 48 33 48 16.2% 1.73 [0.68, 4.36]
Zhou 2022 33 35 28 33 3.9% 2.95 [0.53, 16.38]
Zhou 2023 43 46 32 40 5.3% 3.58 [0.88, 14.58]
Subtotal (95% CI) 207 198 33.4% 2.34 [1.28, 4.30]
Total events 188 161
Heterogeneity: Chi² = 0.90, df = 4 (P = 0.92); I² = 0%
Test for overall effect: Z = 2.75 (P = 0.006)
2.1.2 Distributive shock
Chen 1986 21 21 15 20 0.8% 15.26 [0.78, 296.76]
El-Solh 2010 26 36 24 36 15.7% 1.30 [0.48, 3.56]
Fang 2008 27 32 27 32 9.9% 1.00 [0.26, 3.86]
Guo 2024 37 40 30 40 0.0% 4.11 [1.04, 16.29]
Subtotal (95% CI) 89 88 26.5% 1.63 [0.78, 3.41]
Total events 74 66
Heterogeneity: Chi² = 2.88, df = 2 (P = 0.24); I² = 31%
Test for overall effect: Z = 1.31 (P = 0.19)
2.1.3 other
Yu 2022 99 122 96 137 40.1% 1.84 [1.03, 3.29]
Subtotal (95% CI) 122 137 40.1% 1.84 [1.03, 3.29]
Total events 99 96
Heterogeneity: Not applicable
Test for overall effect: Z = 2.05 (P = 0.04)
Total (95% CI) 418 423 100.0% 1.95 [1.36, 2.81]
Total events 361 323
Heterogeneity: Chi² = 4.66, df = 8 (P = 0.79); I² = 0%
Test for overall effect: Z = 3.60 (P = 0.0003)
Test for subgroup differences: Chi² = 0.61, df = 2 (P = 0.74), I² = 0%
0.002
0.1
1
10
500
Favours [control]
Favours [SB]

Figure 3. Survival.

$P < .00001$). A meta-regression of these 13 studies examined six potential confounders (Year, Study Type, Sample Size, Shock Type, Sampling Time, and Control Group). Shock type ($P = .039$) and control measures ($P = .023$) were identified as primary sources of heterogeneity (Supplemental Material 4).

Funnel plots and Egger test ($P = .273$) indicate no significant publication bias (Supplemental Material 5).

After identifying sources of heterogeneity, subgroup analyses were conducted by shock type and control measures (Supplemental Material 3). During the subgroup analysis of control measures,

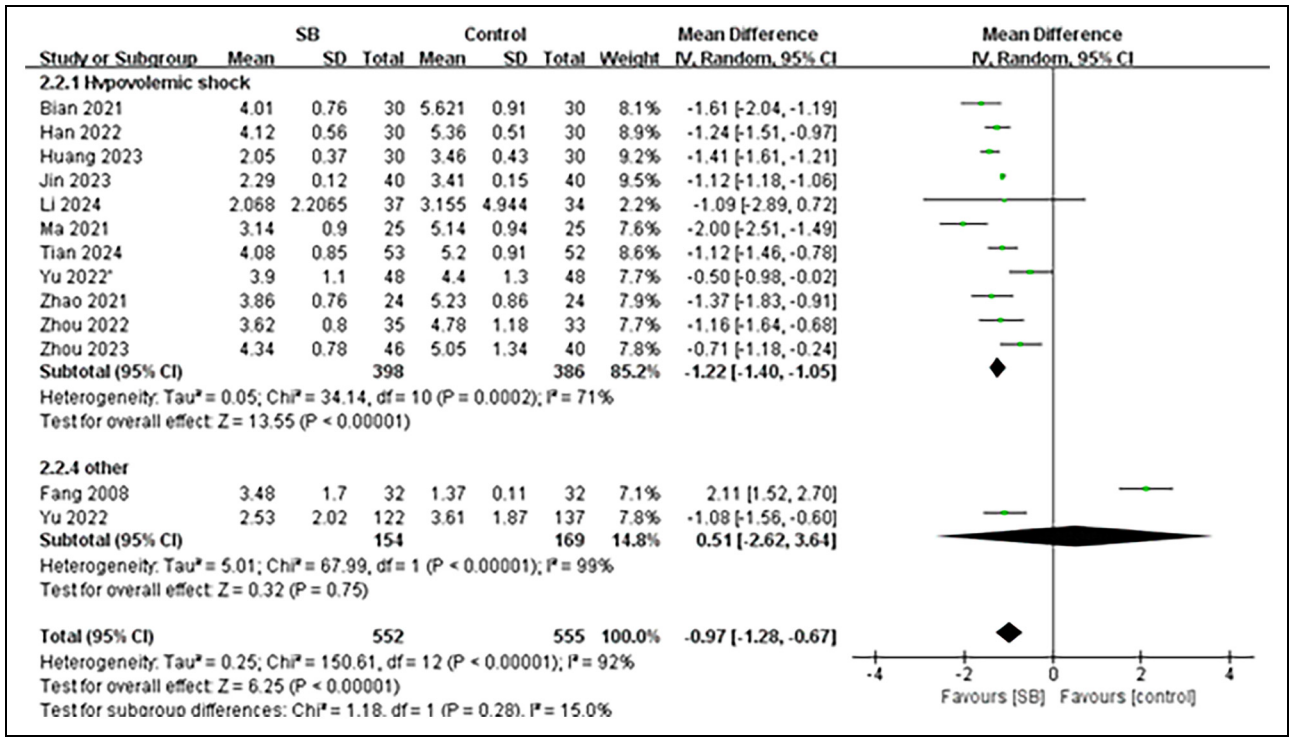

Figure 4. Lac.

one high-bias study in the sodium chloride solution group was identified,[34] showing high heterogeneity and no significant difference between groups prior to its exclusion ($I^2 = 97\%$, $P = .7$). Excluding this study notably reduced heterogeneity, revealing a significant improvement in lactate levels ($I^2 = 30\%$, $P < .00001$), and statistical significance in all subgroups ($P < .05$).

Coagulation Function

Coagulation was assessed using TT (Figure 5a), APTT (Figure 5b), and PT (Figure 5c).

TT

Three studies with low heterogeneity ($I^2 = 27\%$) showed that sodium bicarbonate reduced TT (MD = −2.29, 95% CI −2.45 to −2.12, $P < .00001$) via a fixed-effects model.

APTT

Four studies showed high heterogeneity ($I^2 = 56\%$), which decreased significantly after excluding Zhou et al's study[30] ($I^2 = 0\%$). Sodium bicarbonate lowered APTT (MD = −1.95, 95% CI −2.49 to −1.55, $P < .00001$).

PT

Five studies, analyzed with a random-effects model due to high heterogeneity ($I^2 = 60\%$), found that sodium bicarbonate reduced PT (MD = −0.89, 95% CI −1.4 to −0.38, $P = .0006$).

Inflammatory Factors

IL-6 (Figure 6a), IL-10 (Figure 6b), and TNF-α (Figure 6c) levels were measured to assess the inflammatory response (Figure 6).

IL-6

Analysis of seven studies with significant heterogeneity ($I^2 = 97\%$) using a random-effects model showed that sodium bicarbonate treatment reduced IL-6 levels (SMD = −2.95, 95% CI −4.23 to −1.68, $P < .00001$). Publication bias was detected in the funnel plot and Egger's test ($P = .003$), indicating that publication bias could be a source of the heterogeneity.

IL-10

Four studies were analyzed with high heterogeneity ($I^2 = 97\%$). Excluding the study by Li et al reduced heterogeneity[25] ($I^2 = 0\%$), suggesting that this study contributed to the inconsistency, likely due to unstable sensitivity analysis results. Before exclusion (MD = −0.55, 95% CI −7.04 to 5.94, $P = .87$), and after exclusion ($P < .00001$), the results indicated that IL-10 levels were significantly higher in the sodium bicarbonate group compared to the control.

TNF-α

Seven studies were included, as shown in Figure 6, with substantial heterogeneity ($I^2 = 97\%$). Using a random effects model, the analysis indicated that sodium bicarbonate treatment

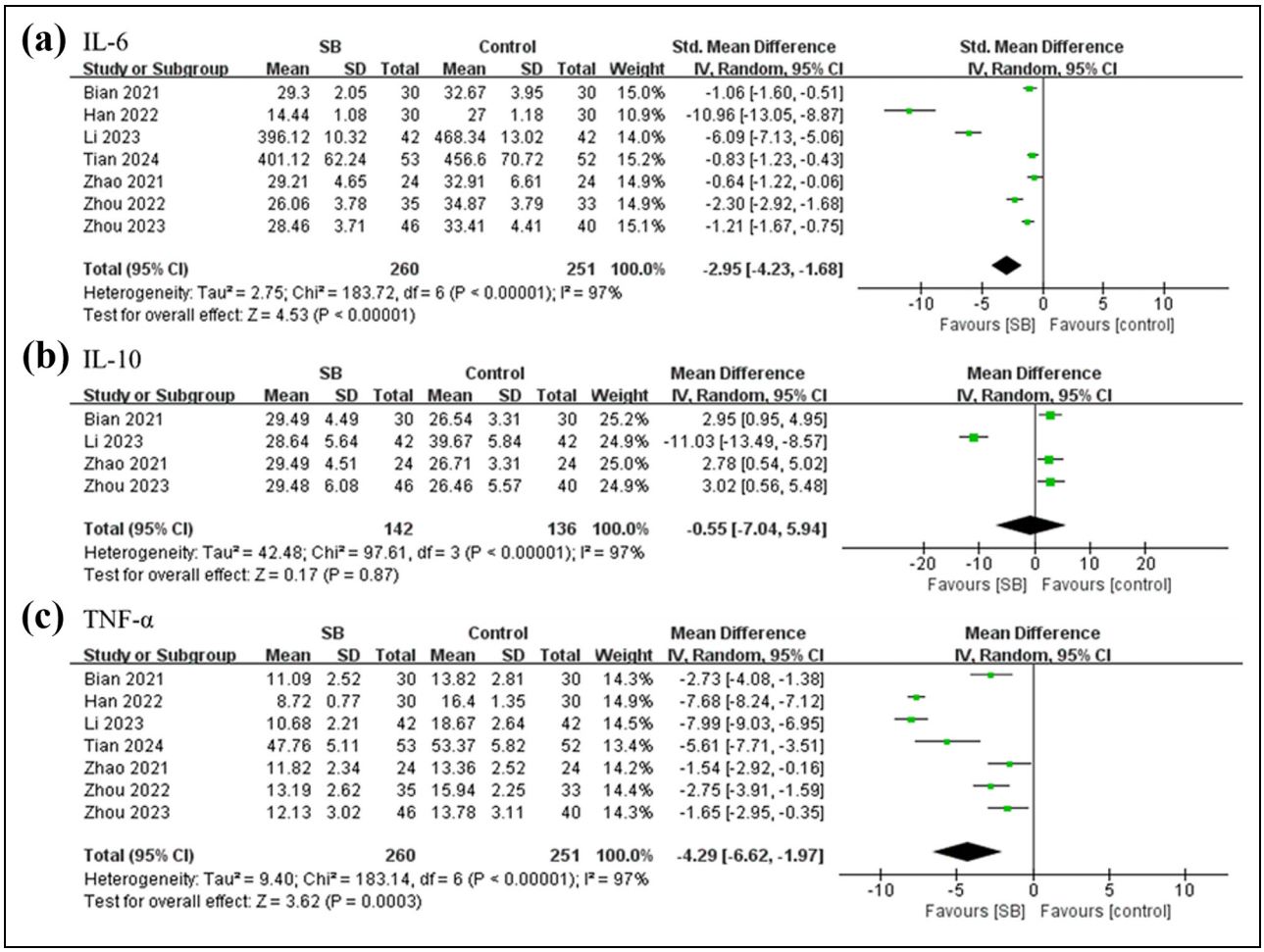

Figure 5. Coagulation function (a) The forest plot of the TT; (b) The forest plot of the APTT; (c) The forest plot of the PT.

significantly reduced TNF-α levels compared to the control group (MD = −4.29, 95% CI −6.62 to −1.97, $P = .0003$).

Complications

We analyzed the incidence of ARDS (Figure 7a), MODS (Figure 7b), and DIC (Figure 7c) across studies. ARDS was assessed in 6 studies, DIC in 3 studies, and MODS in 7 studies (Figure 7). The pooled results demonstrated high homogeneity, with sodium bicarbonate treatment consistently reducing the incidence of these complications compared to the control group.

Other Outcomes

We examined additional outcomes such as respiratory function, vital signs, and electrolyte levels (Supplemental Material 5). Sodium bicarbonate treatment showed no significant effect on respiratory parameters (PO2, PCO2, respiratory rate), MAP, or electrolyte levels (HCO3−, Na+, K+, Cl−). However, it was associated with increased pH and GCS score, as well as decreased heart rate and shock index.

Sensitivity Analysis

We conducted sensitivity analyses for all outcomes. The results revealed that heart rate, K+, and IL-10 were unstable, whereas the remaining outcomes remained stable (Supplemental Material 6).

Discussion

This analysis suggests that Sodium bicarbonate administration in shock patients may be associated with improved survival rates, reduced complication incidence, lower lactate levels, enhanced coagulation parameters, decreased hospital length of stay, and attenuated inflammatory responses.

Shock is categorized into four principal etiologies: hypovolemic, distributive, cardiogenic, and obstructive.[35] While limited-volume resuscitation is clinically established for rapid hemodynamic stabilization and microcirculatory improvement,[36,37] the optimal fluid choice remains contentious. Commonly administered crystalloids—normal saline and lactated Ringer's solution—present limitations.[38,39] Rapid saline infusion carries risks of hyperchloremic acidosis,[40] while lactated solutions may potentially exacerbate existing lactate elevations.[41] In the 1980s, Chen et al administered 5% Sodium bicarbonate to shock patients,

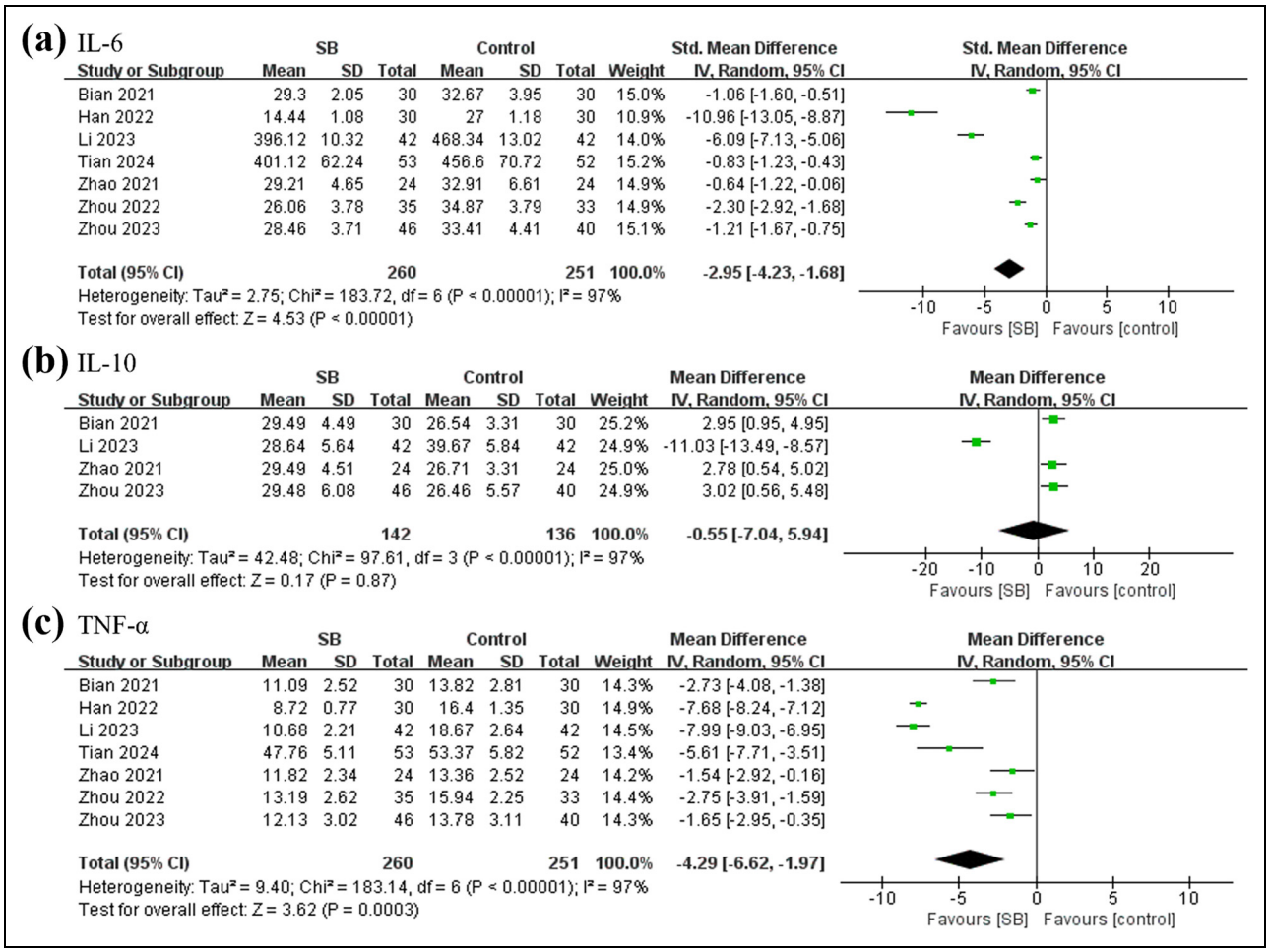

Figure 6. Inflammatory factors (a) The forest plot of the IL-6; (b) The forest plot of the IL-10; (c) The forest plot of the TNF-α.

leveraging its hypertonic properties to expand effective circulatory volume.[32] Clinical studies report associations between Sodium bicarbonate and improved coagulation profiles, reduced inflammatory markers, enhanced survival, and fewer complications. However, its therapeutic role remains debated, particularly in lactic acidosis complicating shock.[8–10] Yu et al observed that Sodium bicarbonate facilitated short-term volume expansion and acidosis correction in hyperlactatemic shock patients.[33] While Sodium bicarbonate's hypertonicity has been theorized to transiently reduce MAP,[8,21] the present analysis found no statistically significant difference in MAP between Sodium bicarbonate and control groups.

A recent systematic review and meta-analysis by Muhammad Ashir Shafique et al, published in February 2024, revealed that sodium bicarbonate may enhance organ stability and improve survival in traumatic hemorrhagic shock patients.[42] In the evaluation review of sodium bicarbonate by Eraky AM et al, although sodium bicarbonate is widely utilized in clinical practice for the treatment of various medical conditions, its application may extend beyond necessary scope and is associated with potential risks.[43]

In subgroup analyses stratified by shock etiology, between-study heterogeneity decreased, may suggesting differential therapeutic applicability of Sodium bicarbonate across shock subtypes. Notably, septic shock patients receiving Sodium bicarbonate demonstrated elevated lactate levels compared to controls. The reason may be that impaired tissue oxygen extraction and microcirculation in septic shock and Increased Glycolytic Flux and Sodium-Potassium Adenosine Triphosphatase Activity Through β2 Stimulation, among others, are more likely to lead to lactic acidosis.[12] Given the ongoing debate regarding Sodium bicarbonate's efficacy in lactic acidosis management,[10,11] these findings may imply potential limitations for its use in septic shock. Notably, strategies exist to mitigate sodium bicarbonate's side effects.

Sodium bicarbonate is most effective in early shock resuscitation and acidosis correction, consistent with pH-timing subgroup analyses in this study.[18,44] This effect is mediated through rapid bicarbonate ion (HCO_3^-) buffering of hydrogen ions (H^+), facilitating prompt acid-base normalization.[45] However, complete acidosis correction is not recommended. Current guidelines support targeted partial correction with concurrent calcium supplementation and ventilatory support to prevent hypocalcemia and CO_2 retention.[12,46] While Sodium bicarbonate rapidly improves acidemia, theoretical risks exist during hypoxic/ischemic conditions where delayed cellular demise may occur. Slow infusion protocols

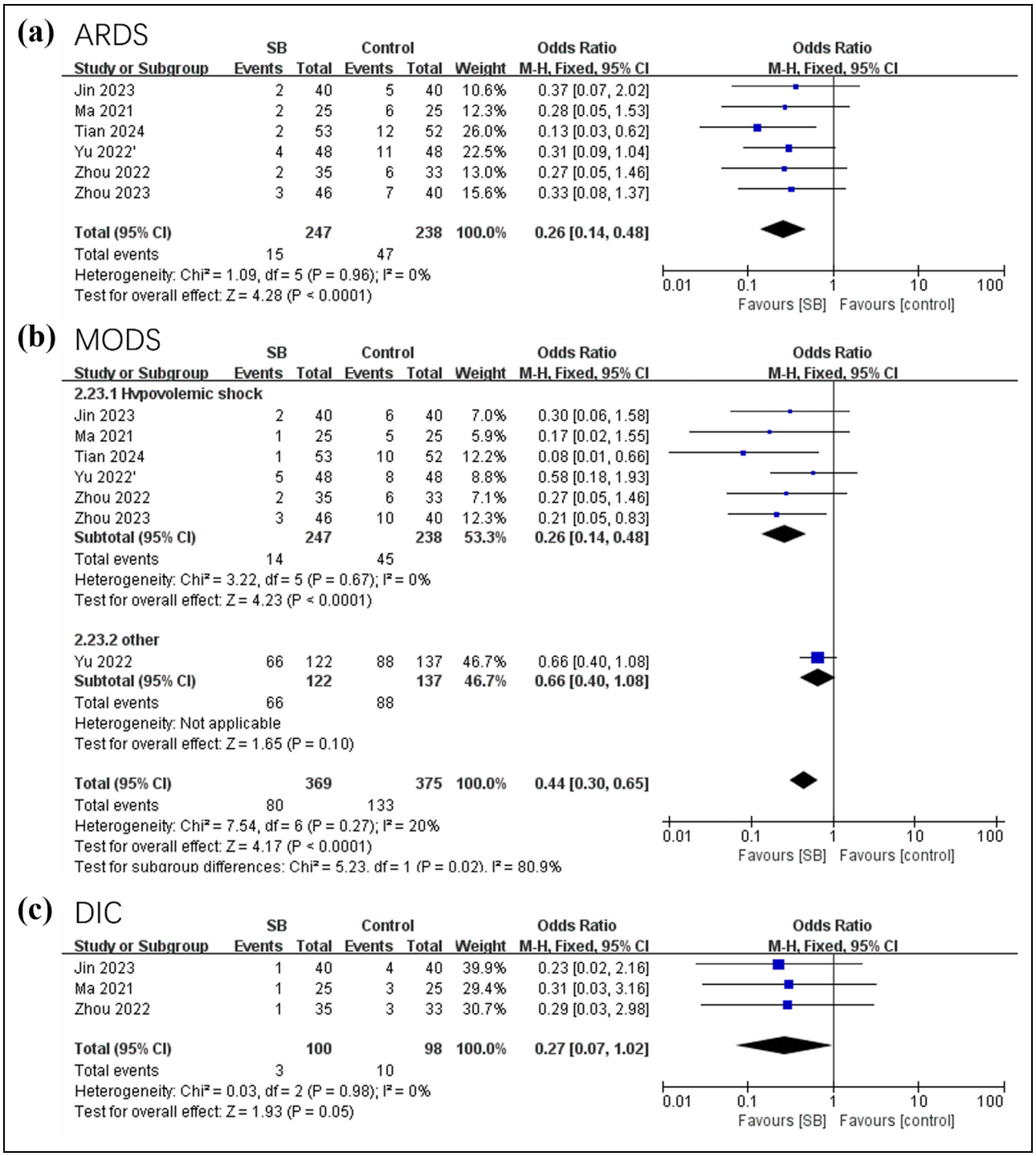
(a) ARDS
SB
Control
Odds Ratio
Odds Ratio
Study or Subgroup Events Total Events Total Weight M-H, Fixed, 95% CI
M-H, Fixed, 95% CI
Jin 2023 2 40 5 40 10.6% 0.37 [0.07, 2.02]
Ma 2021 2 25 6 25 12.3% 0.28 [0.05, 1.53]
Tian 2024 2 53 12 52 26.0% 0.13 [0.03, 0.62]
Yu 2022' 4 48 11 48 22.5% 0.31 [0.09, 1.04]
Zhou 2022 2 35 6 33 13.0% 0.27 [0.05, 1.46]
Zhou 2023 3 46 7 40 15.6% 0.33 [0.08, 1.37]
Total (95% CI) 247 238 100.0% 0.26 [0.14, 0.48]
Total events 15 47
Heterogeneity: Chi² = 1.09, df = 5 (P = 0.96); I² = 0%
Test for overall effect: Z = 4.28 (P < 0.0001)
0.01 0.1 1 10 100
Favours [SB] Favours [control]
(b) MODS
SB
Control
Odds Ratio
Odds Ratio
Study or Subgroup Events Total Events Total Weight M-H, Fixed, 95% CI
M-H, Fixed, 95% CI
2.23.1 Hypovolemic shock
Jin 2023 2 40 6 40 7.0% 0.30 [0.06, 1.58]
Ma 2021 1 25 5 25 5.9% 0.17 [0.02, 1.55]
Tian 2024 1 53 10 52 12.2% 0.08 [0.01, 0.66]
Yu 2022' 5 48 8 48 8.8% 0.58 [0.18, 1.93]
Zhou 2022 2 35 6 33 7.1% 0.27 [0.05, 1.46]
Zhou 2023 3 46 10 40 12.3% 0.21 [0.05, 0.83]
Subtotal (95% CI) 247 238 53.3% 0.26 [0.14, 0.48]
Total events 14 45
Heterogeneity: Chi² = 3.22, df = 5 (P = 0.67); I² = 0%
Test for overall effect: Z = 4.23 (P < 0.0001)
2.23.2 other
Yu 2022 66 122 88 137 46.7% 0.66 [0.40, 1.08]
Subtotal (95% CI) 122 137 46.7% 0.66 [0.40, 1.08]
Total events 66 88
Heterogeneity: Not applicable
Test for overall effect: Z = 1.65 (P = 0.10)
Total (95% CI) 369 375 100.0% 0.44 [0.30, 0.65]
Total events 80 133
Heterogeneity: Chi² = 7.54, df = 6 (P = 0.27); I² = 20%
Test for overall effect: Z = 4.17 (P < 0.0001)
Test for subgroup differences: Chi² = 5.23, df = 1 (P = 0.02), I² = 80.9%
0.01 0.1 1 10 100
Favours [SB] Favours [control]
(c) DIC
SB
Control
Odds Ratio
Odds Ratio
Study or Subgroup Events Total Events Total Weight M-H, Fixed, 95% CI
M-H, Fixed, 95% CI
Jin 2023 1 40 4 40 39.9% 0.23 [0.02, 2.16]
Ma 2021 1 25 3 25 29.4% 0.31 [0.03, 3.16]
Zhou 2022 1 35 3 33 30.7% 0.29 [0.03, 2.98]
Total (95% CI) 100 98 100.0% 0.27 [0.07, 1.02]
Total events 3 10
Heterogeneity: Chi² = 0.03, df = 2 (P = 0.98); I² = 0%
Test for overall effect: Z = 1.93 (P = 0.05)
0.01 0.1 1 10 100
Favours [SB] Favours [control]

Figure 7. Complications (a) The forest plot of the ARDS; (b) The forest plot of the MODS; (c) The forest plot of the DIC.

are therefore advised.[47] Protocolized staged Sodium bicarbonate therapy—combined with mechanical ventilation to ensure CO_2 elimination—may mitigate intracellular acidosis, reduce multiple organ failure (MOF) incidence, shorten ICU and hospital stays, and decrease mortality.[46]

Several limitations warrant consideration. First, while Egger's test and funnel plots were employed, detectable asymmetry suggests possible publication bias (eg, IL-6 analyses), potentially compromising evidence completeness. Second, substantial variation in Sodium bicarbonate protocols—including dosage, concentration, infusion rates, and treatment duration across studies—represents unexplored heterogeneity sources. Third, residual heterogeneity persists in certain outcomes (eg, coagulation parameters) despite subgroup analyses. Sensitivity analyses indicated instability in select results. Only studies in both Chinese and English were included. It is worth noting that in our study, three

studies were retrospective cohorts and five studies did not mention the type of observational nature, which essentially limited causal inference. Finally, evidence for cardiogenic and obstructive shock subtypes is notably limited by sparse data and absence of high-quality RCTs, which leads to a weak evidence base for patients with these specific types of shock and low reliability of the conclusions.

Conclusion

Sodium bicarbonate has demonstrated benefits in treating shock patients, including improved survival rates, fewer complications, better inflammatory responses, reduced lactate levels, and shorter hospital stays. However, its effect on hemodynamics is not obvious. This study offers clinical practice recommendations, though further research is necessary to confirm the broader use of sodium bicarbonate in treating shock.

List of Abbreviations

SB, Sodium bicarbonate; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; SMD, Standardized mean difference; MD, Mean difference; CI, Confidence interval; OR, Odds ratio; ROB, Risk of bias; MODS, Multiple organ dysfunction syndrome; ARDS, Acute respiratory distress syndrome; DIC, Disseminated intravascular coagulation; TT, thrombin time; APTT, Activated partial thromboplastin time; PT, Prothrombin time; PO2, Partial pressure of oxygen; PCO2, Partial pressure of carbon dioxide; MAP, Mean arterial pressure; GCS, Glasgow Coma Scale; HCO3−, Bicarbonate ion; K+, Potassium ion; CL−, Chloride ion; IL-6, Interleukin-6; IL-10, Interleukin-10; TNF-α, Tumor necrosis factor-α; H+, Hydrogen ions; MOS, Multiple organ failure.

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Graphical abstract created in BioRender.com.

Ethics Approval and Consent to Participate

Not applicable.

Consent for Publication

Not applicable.

Authors' Contributions

TAZ conceived the study; drafting the manuscript analysis and interpretation of the data. TAL drafting the manuscript and analysis and interpretation of the data. LWJ performed the data search and assessment of bias. HJL contributed to critical revision of the manuscript for important intellectual content.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Availability of Data and Materials

The dataset supporting the conclusions of this article is included within the article (and its additional files).

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Supplemental Material

Supplemental material for this article is available online.

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